Effects of High Winds

In buildings hit by tornadoes, the threat to life is due to a combination of effects that occur at almost the same time. To understand the tornado damage that can occur in a building, the following must be considered:

- wind-induced forces
- changes in atmospheric pressure
- debris impact

Wind Effects on Buildings

The wind speeds generated by some tornadoes are so great that designing for these extreme winds is beyond the scope of building codes and engineering standards. Most buildings that have received some engineering attention, such as schools, and that are built in accordance with sound construction practices can usually withstand wind speeds specified by building codes. Meeting these code-specified wind speeds can provide sufficient resistance to tornadic winds if the building is located on the outer edge of the tornado vortex. In addition, if a portion of the building is built to a higher tornado design standard, then both building and occupant survival are improved.

Wind creates inward- and outward-acting pressures on building surfaces, depending on the orientation of the surface (e.g., flat, vertical, low-slope). As the wind moves over and around the building, the outward-acting pressure increases as the building geometry forces the wind to change direction. These pressure increases create uplift on parts of the building, forcing the building apart if it is too weak to resist the wind loads. When wind forces its way inside or creates an opening by breaking a window or penetrating the roof or walls, the pressures on the building increase even more. Figure 2-1 shows how wind affects both an enclosed building and a building with openings.

Heavy building materials (e.g., reinforced masonry or concrete) that are well tied to all other building components often survive extreme winds. The weight of these materials helps resist uplift and lateral loads, and heavy materials often stop windborne debris that can increase damage to the building. However, heavy concrete roof panels and heavy masonry walls that are not adequately connected or reinforced have failed during severe winds. Lightweight roofing and siding materials such as gravel, insulation, shingles, roofing membranes, and brick veneer can also be a problem.

Building shapes that “catch” the wind, such as overhangs, canopies, and eaves, tend to fail and become “sails” in extreme winds. Flat roofs can be lifted off when the wind flows over them and increases the uplift pressure at the corners and edges of the roofs.

Atmospheric Pressure Changes

Initially, the pressure outside a building during a tornado is very low compared to the pressure inside. In most buildings, however, there is enough air leakage through building component connections to equalize these pressures. Also, windborne debris is likely to break windows and allow wind to enter.

The explosion of buildings during a tornado due to atmospheric pressure differences is a myth. In reality, the combination of internal pressure and outward pull on the building from suction pressure has caused building failures that have forced the walls outward and given the building the appearance of having exploded. During an event, doors and windows should remain closed on all sides of the building in order to minimize the entry of wind into the building.

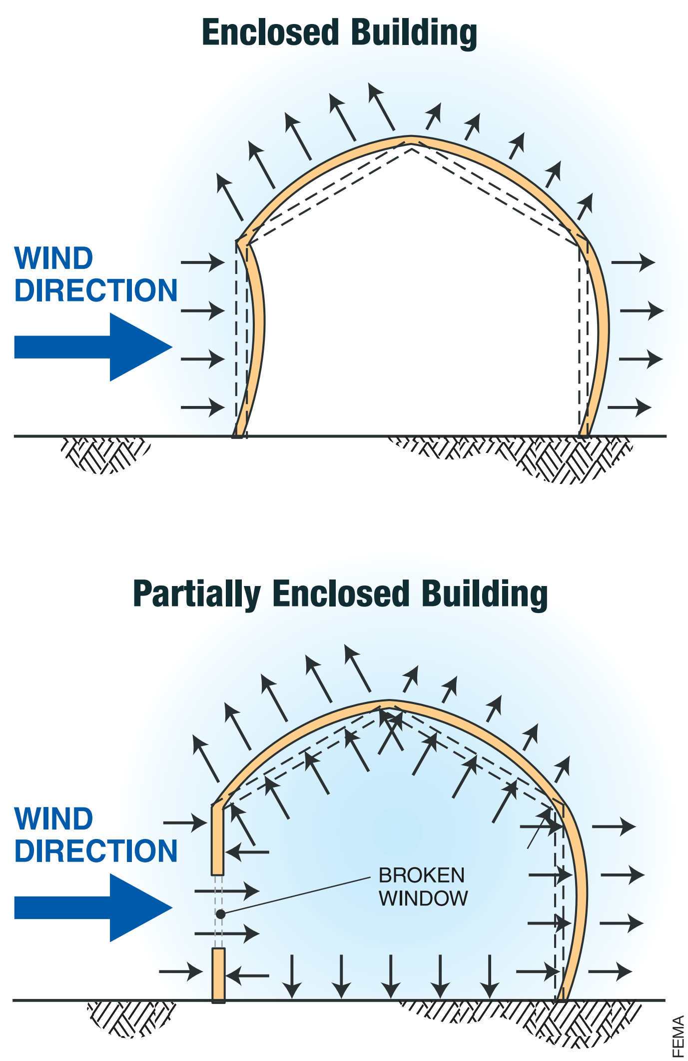

Figure 2-1
Effects of wind on a fully enclosed building and on a building with openings.

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Figure 2-2
Example of damage from a windborne missile. A 2-inch by 6-inch board penetrated a refrigerator.

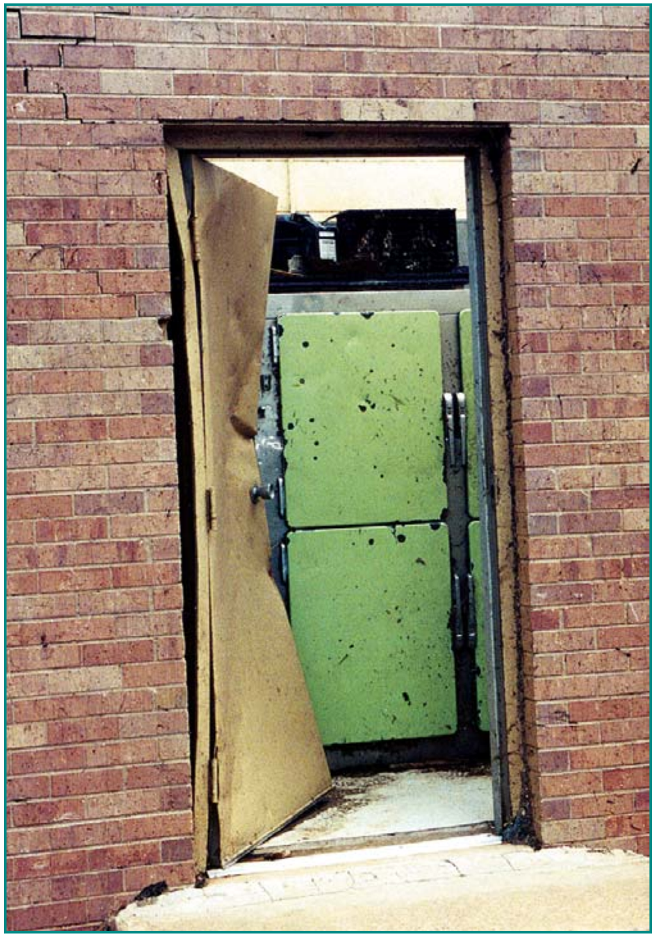

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Figure 2-3
Example of severe damage from a windborne missile. This metal door was pushed inward by the impact of a heavy object.

Debris Impact

The extreme winds in tornadoes pick up and carry debris from damaged buildings and objects located in the path of the winds (see Figures 2-2 and 2-3). Even heavy, massive objects such as cars, tractor trailers, and buses can be moved by extreme winds and cause collateral damage to buildings. Light objects become flying debris, or missiles, that can penetrate doors, walls, and roofs; heavier objects can roll and cause crushing-type damage.

Missiles can travel vertically as well as horizontally (see Figure 2-4). Therefore, shelters and refuge areas should provide protection overhead as well as on the side. Building walls and roofs can be designed to withstand the impacts of these missiles. Protection can be provided at the exterior building wall, or interior barriers can be constructed to provide protection for a smaller area within the building.

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Figure 2-4
Example of damage from windborne missiles. Medium and small missiles penetrating through the roof of a high school. The missile protruding from the roof in the foreground is a double 2-inch by 6-inch wood board. The portion sticking out of the roof is 13 feet long. This missile penetrated a ballasted ethylene propylene diene monomer (EPDM) membrane, approximately 3 inches of polyisocyanurate roof insulation, and the steel roof deck. The missile lying on the roof just beyond it is a 2-inch by 10-inch, 16-foot-long wood board. The missile protruding from the roof in the background is a 2-inch by 6-inch, 16-foot-long wood board.

Selecting Refuge Areas

Wind effects on buildings have been studied sufficiently to predict which building elements are most likely to successfully resist the extreme wind pressures caused by tornadoes and which are most likely to fail. Sufficient material testing and design work has been performed for large shelters to develop a refuge area selection guide for any building in which such areas are needed. Many buildings contain a small interior area or areas that could serve as the best available refuge area or possibly be converted or reinforced for refuge area use.

The selection of refuge areas in existing buildings is discussed in Chapter 4. For more information about refuge areas and shelter design, refer to FEMA publication 361, *Design and Construction Guidance for Community Shelters* (see sidebar on page 11).